EUV Laser Research at the University of Berne

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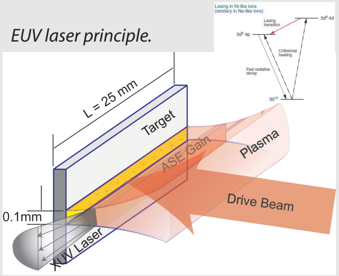
Introduction.

The University of Berne's EUV laser is a high brigthness (>10^{25} ph s^{-1} mm^{-2} $mrad^{-2}$ 0.1%BW) and narrow linewidth ($\Delta\lambda/\lambda$= 10^{-5}) clean photon source. A hot-dense plasma column is the gain medium to amplify spontaneous emission (ASE) and lead to laser radiation in the range 5-50nm, depending on the target. The footprint of the facility is <$5m^2$, which makes it a "laboratory scale" system. This offers the opportunity to enable accessible cost-of-ownership applications such as:

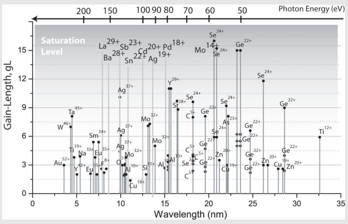
- *XUV Coherent Imaging*, which significantly enhances resolution and contrast;
- *XUV Photoelectron Spectroscopy*, which enhances resolution and tunability.

In order to improve our understanding and the technology performance we are also committed to fundamental studies of XUV and laser plasma.

EUV laser principle.



EUV laser lines: those saturated in our lab are highlighted on top.



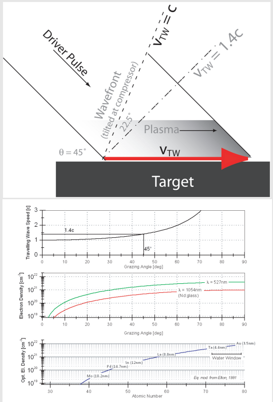
1. XUV Laser & Plasma Fundamentals

> **Grazing Incidence Pumping** (GRIP) allows saturating EUV laser lines with table-top driver systems. The incidence with 10-30° induces travelling-wave pumping which sustains ASE across the hot-dense plasma. In our system two **major innovations** are introduced:

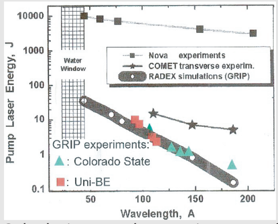
- *Tilted wavefronts*, which significantly improves travelling-wave pumping to match the speed of light along the target surface. The wavefronts are tilted at the compressor grating with irrelevant time dispersion;

- *On-axis pre-pulses*, which improves spatial overlapping with main pulse with respect to "transverse pre-pulse" scheme. Two pre-pulses are delivered to produce a plasma, relax density gradients, trigger massive closed shell ionization (Ni-like), and population inversion.

> Our original technique has facilitated the access to lines below 13nm with just a few joules pump, which is a factor of 10 improvement to traditional pumping requirements. This is promising in the perspective to achieve the "water window" for bio-imaging applications.

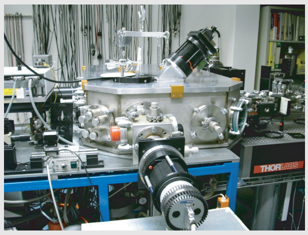


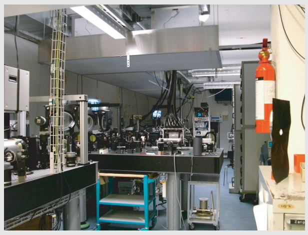
Travelling-wave concept.



Calculation and experiments of energy requirements.

2. Experimental Facility





> **Source:** Single-shot 4 TW driver laser based on regenerative amplifier+ Nd:glass amplifiers (EUV specs on table below); 5Hz EUV laser using OP-CPA architecture under construction.

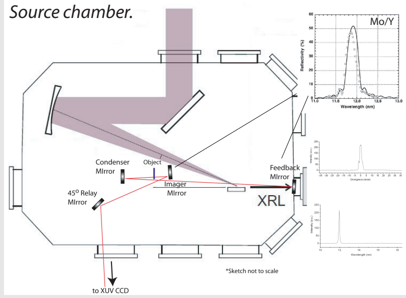
>**Chamber:** 10^{-4}mbar (source stage), 10^{-6}mbar (exposure stage).

> **EUV optics:** Mo/Y multilayer. No damage for exposures tests up to 1000 shots.

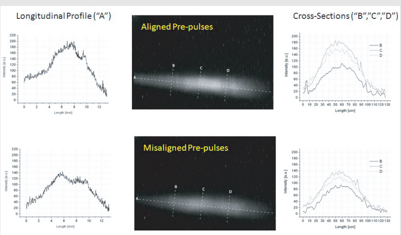
>**Diagnostics:** Phosphor Plate+CCD, XUV-CCD, Streak units, Autocorrelator .

Specification	EUV Laser
Energy	5µJ
Pulse duration	5ps
Power	1MW
Photon budget	10^{11}
Fluence	500mJ/cm^2
Brightness	>10^{25} ph. unit.
Wavelength	12nm
Rel. Linewidth	0.001%
Spatial Coherence	5 x 10 um

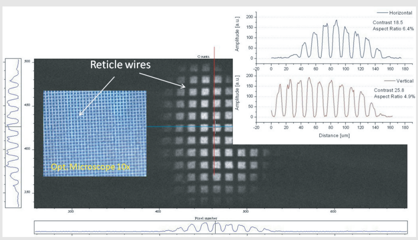
Source chamber.



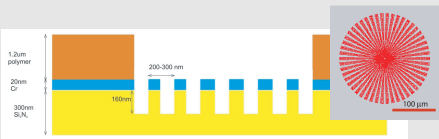
3. EUV Imaging



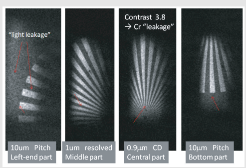
> **Plasma Imaging:** using a pinhole camera, with 20x transverse magnification, we visualized the structure of the plasma column, based on its spontaneous emission and phosphor screen detection. Longitudinal and cross-section profiles are shown here.



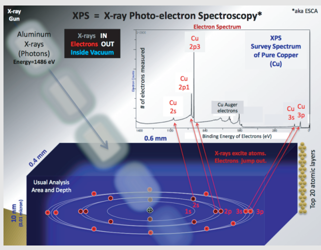
> **EUV Transmission Microscopy:** using a back-illuminated XUV CCD camera and Mo/Y optics, we visualized micron-scale objects with a field-of-view of 100 x 50um. EUV images of a reticle and of a Siemens star (0.2-10um) are shown here.

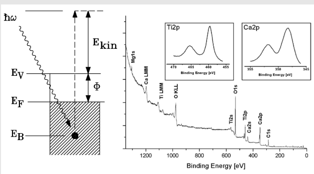


Siemens star sample.

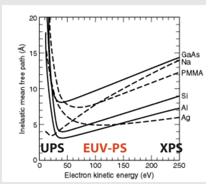


4. EUV Photoelectron Spectroscopy





Principle of photoelectron spectroscopy.



Penetration depth of PES.

> Photoelectron spectroscopy (PES) relies on the kinetic energy of photon-induced secondary electrons. This permits to infer the binding energy and the electron density of states. Angle-Resolved PES gives insigths also on the electron momentum dispersion in the solid lattice.

> Depending on the photon energy, the penetration depth can vary. DUV lamps are used in UPS to increase the bulk sensitivity. X-ray sources are used to access high energy density of states, though the source line-width is limiting to high resolution studies. A region in-between is characterized by the highest surface-sensitivity, i.e. surface contamination study.

Advantages of the EUV laser for PES are:

-Discrete line tunability;
-50-150eV variable photon energy;
-Narrow linewidth <10meV ;
-ARPES and pump-probe capability;
-Laboratory scale.

Conclusions. A complex EUV laser has been developed in the last 10-15 years, which is now used for applications. These range from EUV imaging in lithography to EUV angle-resolved photoelectron spectroscopy. The combination of the two offers a lab-scale facility capable of chemical and morphological nano-mapping.

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